Electrochemical supercapacitors of Self-Grown Ni-based electrode materials

Synopsis in Candidature for the Degree of
Doctor of Philosophy in Physics

Submitted by

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1. Introduction:

Significant shift in the global climate and the shortage of fossil fuels require the society to acquire green energy. Energy is one of the most essential aspects in the 21st century living and nonliving entities including human, animal and environment. Energy production and consumption, a function of combustion of fossil fuel, is going to disturb the world economy if not considered seriously. So, there has been an increasing demand for environmentally friendly, high-performance, and cost-effective renewable energy storage devices [1, 2]. Since last two to three decades, electrochemical supercapacitors (ESs) have gained significant attention due to their high-power density, longer cycle life than batteries, and higher energy density than conventional dielectric capacitors and batteries. Such outstanding advantages have forced them for hybrid electric vehicles, digital cameras, industrial equipment's, and other renewable energy storage devices. Also, due to a fast-growing market for portable electronic devices, such as mobile phones, notebooks, laptops, computers, and their development trend of being small, lightweight, and flexible, have brought about an ever-rising and urgent demand for eco-friendly electrochemical energy storage and conversion systems that are lying between capacitors and the batteries [3-7].

In order to mitigate the serious worries concerning energy disaster, numerous substitute technologies have come up into reality [5]. In upcoming days, ESs will be painstaking as a significant model in technology due to the acceptance of energy storage systems [3]. Nowadays, ESs can be a good alternative to batteries which offer raised power densities, density, and stable, long discharge time [7]. ESs of carbonaceous electrodes demonstrate electrochemical performance but long lasting cycle life whereas carbonates or conducting polymer-based materials reveal low operating potential window and a weaker chemical/environmental stability. However, recently developed symmetric/ asymmetric ESs devices can achieve reasonably high energy density as well as high power density along with a larger operating cell voltage [8].

The current collector is an important component of ESs and is oftenly used as the substrate on which further material fabrication is being done for symmetric/asymmetric supercapacitor devices. In this proposed work, we will use nickel foam (Ni) as a substrate as a current collector and 3D-structured self-grown Ni-based electrodes such as NiO, NiS, NiSe, and NiSSe etc. will be synthesized by using one of the following chemical methods for electrochemical supercapacitor fabrication.

2. Literature review:

Fabrication of such asymmetric or symmetric devices often requires active material combinations such as metal oxide, metal oxide/MXene, conducting polymers, metal oxide/carbon-based materials, etc., a suitable electrolyte, and a current collector (substrate) [9-11]. The current collector is an important constituent of ESs and is often used as the substrate on which further material fabrication is done for the electrodes of asymmetric/symmetric supercapacitor devices. Substrates such as graphite [9], gold (layer) on glass [12], aluminum [13], stainless-steel [14], carbon cloth [15], Si-Pt based foils [16], nickel-based metallic foams [17-18], etc., are commonly used in electrochemical energy storage devices as current collectors as well as active mass supporters. The active material nanostructures supported on 3D substrates facilitate larger surface area, easy electrolyte access to the electrode, efficient electron transfer, and faster ion transportation, which has allowed electrodes to achieve high contact areas for promoting the ion transportation rate, improving the utilization of electrochemically active materials [19] for optimum performance.

NiF-based symmetric/asymmetric electrochemical supercapacitor investigations have recently gained considerable attention due to their 3D structure, high electrical conductivity, low cost, and relative abundance [20]. Despite decades of knowledge on Ni oxides in strong bases and the fact that Ni-foam has been vigorously used as a base material in the majority of the reported studies, little attention has been paid to its own properties. In general, the mass of active material is typically the difference between Ni-foam plus active material and that of Ni-foam itself. This measurement translates to specific capacity and related calculations when used to store charge. Often, the Ni-foam is used as the support material on which another electrode material is grown, often in air and at relatively high temperatures [18-19], which affects the grain structure and composition of the surface phase of the Ni.

Therefore, by considering and reviewing the importance of nickel foam as a current collector, it is planned to synthesize NiO, NiS, NiSe, and NiSSe self-grown electrodes using one of the following appropriate chemical techniques for fabricating asymmetric and symmetric supercapacitor devices.

3. Significance of the study

The proposed Ni-based electrode process used for supercapacitors is expected to have a high energy density. These peculiar properties may be attributed to appropriately evolved control and regulation of Ni-based electrodes for supercapacitors in which certain Ni-based electrodes for supercapacitors will play a vital role. Such Ni-based electrodes for supercapacitor compounds usually have definite conformations which are of critical significance for them in the field of energy and storage. Therefore, it will be of the high importance to elucidate the nature of the pertinent Ni-based electrodes for supercapacitors and their functional potentialities. Therefore, the study of the Ni-based electrode for

supercapacitor will be helpful in understanding the Ni-based electrode for supercapacitor in different environments (i.e. temperature, concentration, remarkable safety, a very large interlayer spacing, environmental flexibility, a large surface area, and thermal conductivity, etc.) using the various physical parameters.

4. Objectives

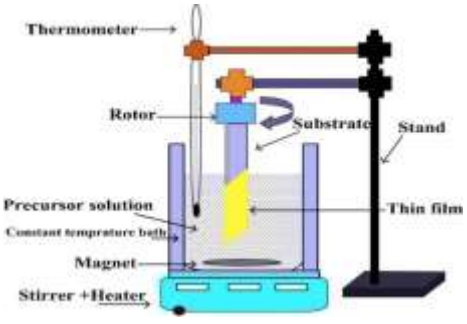
The main objectives of the proposed research work are to carry out and study a self-Grown Ni-based electrode for supercapacitor applications.
This study will focus on.

1. Using reducing complexing agents, create self-grown Ni-based electrode materials.
2. Synthesis of 3D structured Ni-based electrodes such as NiO, NiS, NiSe, and NiSSe.
3. The morphological and electrochemical properties of the prepared materials will be thoroughly investigated.
4. Structural and surface morphological properties of the self-grown Ni-based nanostructured electrodes will be studied using various characterization techniques such as X-ray diffraction, field emission scanning electron microscope, high resolution transmission electron microscopy, X-ray photoelectron spectroscopy energy dispersive X-ray spectroscopy, Fourier Transform Infrared Spectroscopy, and Raman spectroscopy, etc.
5. Obtained high specific capacitance, cyclic life, and excellent rate capability.
6. Fabrications of symmetric and asymmetric supercapacitor.
7. Work will be published in reputed journals.

5. Synthesis Methods

Several chemical methods are used for synthesis of self-grown Ni-based and composite electrodes such as hydrothermal deposition (HD), chemical bath deposition (CBD), electrodeposition (E-D), successive ionic layer adsorption and reaction (SILAR), sol-gel, and spray pyrolysis deposition (SPD), have frequently been used to obtain Ni-based nanostructures in both film and powder form. Few methods are as follows;

5.1 Wet chemical method



The metal oxide/Ni-based electrode prepared by adjusting CBD preparative parameters, such as deposition temperature, time, pH, complexing agent etc., as shown in Fig. 1. The metal oxide films were deposited from the solution containing precursor by using different complexing agent.

Fig.1 Chemical bath deposition.

5.2 Successive ionic layer adsorption and reaction

Successive ionic layer adsorption and reaction i.e. SILAR method is economical, highly feasible for large area deposition. For the deposition of material in thin film, a well-cleaned glass substrate need to be immersed in the cationic precursor solution, causing cations to be adsorbed on the surface of the glass substrate. This substrate should then be immersed in an ample amount of double distilled water to prevent homogenous precipitation. The substrate would then be immersed in the anionic precursor solution. Anions reacted with the adsorbed cations on the glass substrate. The substrate was then immersed in double-distilled water.

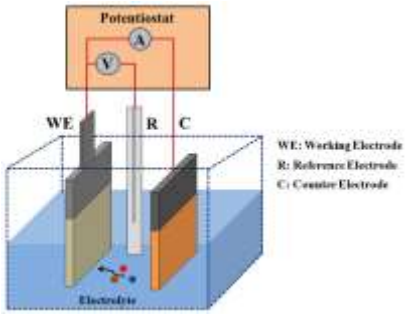
5.3 Hydrothermal

Several metal oxide have been successfully synthesized by using the hydrothermal method. There are significant advantages of hydrothermal synthesis method over others. Hydrothermal synthesis can generate nanomaterials that are not stable at elevated temperatures. Nanomaterials with high vapor pressures can be produced by the hydrothermal method with minimum material loss. The compositions of nanomaterial to be synthesized can be well controlled in hydrothermal synthesis through liquid phase or multiphase chemical reactions.

5.4 Electrodeposition method

Electrodeposition is a well-known conventional surface modification technique to improve the surface characteristics, both decorative and functional, of a wide variety of materials. It is a versatile and inexpensive technique that can be performed at mild temperatures (≤100°C) which will minimize interdiffusion of materials in the case of a multilayered thin-film preparation. The film thickness can be controlled by monitoring the amount of charge delivered, whereas the deposition rate can be followed by the variation of the current with time, and the schematic arrangement of the electrodeposition arrangement, which is shown in Fig. 2. This is based on controlled current or controlled potential electrochemical deposition on an electrode from a solution containing the appropriate species. Therefore, the electrodeposition method is frequently used for the deposition of a wide range of compounds, including metals, semiconductors, mixed metal oxides, and magnetic structures.

Fig. 2. Electrodeposition Set-up.



6. Experimental section

Synthesized self-grown Ni-based electrodes will be characterized by using different analytical tools and techniques such as X-ray diffraction, Raman spectroscopy, Fourier Transform Infrared Spectroscopy, Field Emission Scanning Electron Microscopy, High Resolution Transmission Electron Microscopy (HR-TEM) X-ray photoelectron spectroscopy (XPS), energy dispersive X-ray spectroscopy (EDS), etc.

An Electrochemical workstation will be used to study the electrochemical properties and device fabrication. Finally, carried work will be submitted to the university for the award of a Ph.D. in the form of a thesis.

7. *Work plan*

The proposed work will be carried out in following phases;

Phase – I (First Year)

- In the first year, a literature survey will be carried out. The various self-grown Ni-based materials will be prepared using suitable synthesis methods.

Phase – II (Second Year)

- The electrochemical performance of the prepared metal sulphides will be measured and studied in different electrolytes such as KOH, H_2SO_4, NaOH, KCL, etc.
- A Reducing complex agent will be used to synthesis of self-grown Ni based electrode.

Phase – III (Third Year)

- The symmetric and asymmetric devices will be built to investigate the industrial potential of the prepared metal sulfides.
- The work will be published in the form of research manuscripts in high impact research journals.

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